# SECTION 1A

# HULL PERFORMANCE



## 1A.1 REFERENCES

(Not Used)

## 1A.2 INTRODUCTION

This Section contains the Contractor Design and Provide requirements for the performance of the hull, propeller, and the Propulsion and Propulsion Control Systems.

***For WSF system standardization purposes, End No. 1 of the Vessel shall always be considered the bow, and this designation shall delineate port and starboard, fore and aft wherever they are addressed in the Technical Specification.***

## 1A.3 GENERAL

### 1A.3.1 Definitions

Throughout this Section the following definitions apply:

A. ***Continuous service rating*** - The "ISO Standard Power" determined in accordance with ISO 3046/1 for continuous marine propulsion duty. For the purposes of this Section the continuous service rating is considered to be the power output at any specified engine RPM between idle and full rated RPM, for continuous marine service, for a diesel engine. Continuous service is intended to describe operations, at the rated power output, twenty-four (24) hours a day for periods nominally on the order of 365 consecutive days.

B. ***Maximum continuous service rating*** - The maximum value of the continuous service rating function given above.

C. ***Design operating draft*** - Draft corresponding to the delivery lightship weight, plus 312 long tons representing operating loads and consumables, plus an average deadweight load of 403 long tons for Passengers and Vehicles.

D. ***Mid-service-life draft*** - Draft corresponding to the delivery lightship weight, plus 225 long tons representing half of all service life margins, plus 312 long tons representing operating loads and consumables, plus an average deadweight load of 403 long tons for Passengers and Vehicles.

E. ***End-of-service-life draft*** - The maximum operating draft at the end of a nominal sixty (60) year service life. The weight associated with this draft and displacement is to include 450 long tons representing all service life margins, 366 long tons representing operating loads and consumables, a maximum weight load of 686 long tons for Passengers and Vehicles. The end-of-service-life draft presumably equals, but may not exceed, the navigation draft limit of 18'-0".

F. ***WSF's optional hull form*** - Where reference is made to "WSF's optional hull form", a **FIGURE 1A-1,** *LINES PLAN (2 sheets)*, attached to the end of this Section of this Technical Specification provides a representation of the salient features of optional hull form lines and is intended to amplify the words contained herein.

### 1A.3.2 Hull Form

***It is not the intention of WSF to specify the hull form, or to inhibit Contractor innovation with respect to the hull form, or to prevent the Contractor from developing the hull form in such a way that the Contractor can efficiently produce the hull***. However, WSF is very interested in receiving a hull form that has low annual fuel consumption, minimized wake wash, good maneuvering, and minimum propeller induced vibration. In the interest of achieving these objectives WSF has taken certain steps during the development of their detailed WSF Requirements, such as:

1) nonlinear free surface computational fluid dynamic analysis with optimization to select a hull form for minimum resistance;
2) scale model tests at STATENS SKEPPS PROVNINGS ANSTALT (SSPA), Sweden, for maneuvering, and calm water resistance and power, and detailed 3-D wake survey.

The results of these efforts have been used to establish WSF's expectations and the detailed WSF requirements with regard to hull performance. The results of these efforts are available to Contractors preparing designs for this Vessel. WSF does not warrant the accuracy or adequacy of the studies already accomplished. The Contractor is charged with judging the accuracy and adequacy of those studies, and taking those steps deemed prudent and necessary by the Contractor to assure that the hull form proposed by the Contractor, whether it be WSF's optional hull form, or an alternative developed by the Contractor, can meet the performance requirements of these Technical Specifications. In any event, these Technical Specifications impose requirements for additional scale model testing and other hull, appendage and propeller related engineering design efforts on the Contractor's design processes.

While shipyards proposing the optional hull form developed by WSF may choose to rely on the engineering analysis and scale model testing efforts already accomplished, WSF does not believe that it is in WSF's interest to permit the Contractor to rely on this prior work should the Contractor's hull form deviate more than a minimal amount from WSF's optional hull form. The following criteria describe deviations from the WSF-developed optional hull form, any one of which may result in a WSF determination that new model tests (including a repeat of some or all of the test program elements previously conducted on behalf of WSF by the New Ferry Design Team (NFDT) at SSPA, Sweden) will be required during Phase II Technical Proposal development:

A. A change, when compared to the WSF optional hull form, exceeding 1-percent (1%) in the displacement at any corresponding waterline between 14.0 and 18.0 feet above baseline.

B. A change exceeding 1-percent (1%) in the design waterline length (DLWL) or in the design waterline beam ($B_{WL}$), where the design waterline is here understood to correspond to the 16.45 ft draft.

C. A change exceeding 1-percent (1%) in the block coefficient ($C_B$), maximum section coefficient ($C_M$), longitudinal prismatic coefficient ($C_P$), vertical prismatic coefficient ($C_{VP}$), or waterplane coefficient ($C_{WP}$) determined at the design waterline, where these coefficients are evaluated at a waterline corresponding to the 16.5 ft. draft.

D. A change in the sectional area of any section, measured to any waterline between 14.0 and 18.0 feet above baseline, which exceeds 2-percent (2%) of the corresponding sectional area of the baseline design.

E. Any section which locally so deviates from the corresponding WSF optional hull form section that a six (6) inch diameter circle can be located between the section curves. This criterion is to be applied from the keel to the 19.0 ft. waterline.

F. Any section where the root mean square deviation of the Contractor proposed section measured with respect to the corresponding WSF optional hull form section exceeds two (2) inches. Deviations are to be measured from the WSF optional hull form section to the Contractor proposed section along lines which are normal to the WSF optional hull form section. The root mean square deviation is to be determined by integrating the squared deviations so measured from the keel to the 19.0 ft. waterline.

G. Waterline half entrance angle at waterlines between 14.0 feet and 18.0 feet above baseline, which differ from the corresponding half entrance angles of the WSF optional hull form by more than one (1) degree.

H. Introduction of any additional chines or knuckles to the underwater hull form. Any new chine or knuckle extending more than 60-percent (60%) of the hull length, or any new chine or knuckle for which the interior angle is less than 165 degrees over a distance, measured along the chine, of ten (10) feet or more, will be deemed to be a chine for the purposes of this criterion.

I. Any change exceeding six (6) inches in the design propeller diameter or in the vertical location of the propeller hub, or any change exceeding two (2) feet forward or aft in the longitudinal location of the propeller hub.

J. Any change exceeding 2-percent (2%) in the design movable surface area of the rudder design, or 5-percent (5%) of the rudder span, or 10-percent (10%) in the geometric aspect ratio of the rudder.

The intent of the foregoing criteria is to permit ordinary fairing of the WSF optional hull form, as would be expected when proceeding from Preliminary to Phase II Technical Proposal. The criteria have also been developed with the intent that it be possible, if the Contractor so chooses in order to accommodate his production methods, to modify the WSF optional hull form between the knuckle at the flat of keel and the lower bilge tangent to either “straight” frames or a true developable surface, without necessarily altering the WSF optional hull form more than a minimal amount.

If the Contractor proposes a hull form which deviates from the WSF optional hull form, the determination of the WSF Representative regarding whether or not it is acceptable for the Contractor to rely on the engineering analysis and scale model tests performed by SSPA Sweden, shall be final. WSF may also determine which segments of the previously accomplished test program need to be repeated. This determination is not intended to hinder the Contractor from performing a separate analysis or performing any model tests the Contractor believes are necessary, including repetition of tests previously performed on behalf of WSF.

If the Contractor proposes a hull form with additional chines or knuckles below the deepest load waterline, then calm water resistance and self propulsion tests must be performed at least at two (2) different waterlines which reasonably represent the range of operating conditions expected over the sixty (60) year service life of the Vessel.

WSF may accept Computational Fluid Dynamic (CFD) Analysis in lieu of physical model testing. The prerequisite for such consideration is submittal of a professional correlation study demonstrating satisfactory agreement between the proposed CFD analysis method and physical model tests. Such correlation studies will be most favorably regarded if the correlation is demonstrated for a close parent hull for the proposed WSF New 144-Auto Ferries Project. Alternatively, correlation studies that demonstrate consistently good agreement for a family of hull forms for which the proposed hull form could be regarded as an ‘interior’ family member, will also be considered. Correlation must be demonstrated for the response processes of interest. The WSF decision regarding the acceptability of CFD in lieu of physical model testing for a specific application shall be final.

All expenses associated with any analysis or model testing required by WSF as a consequence of the Contractor’s hull form deviating from the WSF optional hull form by more than a minimal amount shall be the sole responsibility of the Contractor and shall not result in a change order, or additional cost to WSF. Such expenses extend to the cost of redesigning and providing replacement wake adapted propeller blades designed and manufactured specifically to fit the Owner - Furnished controllable pitch propellers, in accordance with, and meeting the design requirements of, this section of the Technical Specification.

## 1A.4 MODEL TESTING

### 1A.4.1 Standards for Model Basins

The model scale ratio for calm water testing shall not exceed 18.9:1. For the purposes of this requirement, calm water testing shall include bare hull and appended resistance, any open water propeller tests, self-propulsion tests, measurement of wave signatures, flow visualization and flow alignment, and detailed wake surveys in the propeller plane. Notwithstanding the foregoing, the model scale for self-propulsion tests and detailed wake surveys shall be such that the model propeller diameter is no less than 7.3 inches.

The model scale for maneuvering tests, if different from that for other calm water testing, shall not exceed 30:1.

The main deepwater towing tank facility proposed for calm water tests (i.e., flow visualization, resistance, propulsion, and detailed wake survey) should have a minimum width of 30 feet (9.1 m) and a minimum water cross sectional area (width times water depth) of 500 square feet (46.5 $m^2$). The deepwater towing tank should be at least 300 feet (91.4 m) long, but longer length is preferred.

The model test facility shall have recent experience testing Vessels of similar hull form, proportions and general service characteristics. Preference shall be accorded to model test facilities that, as a minimum, have tested at least three (3) double-ended ferries in the past ten (10) years.

### 1A.4.2 Model Test Programs

Model testing during the Phase II Design development shall include flow visualization, bare hull and appended resistance, self-propulsion, measurement of wave signature, and detailed wake surveys in both bow and stern propeller planes and maneuvering. **Refer to the *DETAILED WAKE SURVEYS* Subsection in this Section of the Technical Specification, for further description of wake survey requirements**.

Model tests of the final design propeller are not required unless propeller design calculations, as described in the *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification, indicate that:

1. the predicted margin against exceeding the cavitation limits, as specified below in the *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification, is very small; and/or
2. the predicted margin against exceeding the limits, specified below in the *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification, for the propeller induced pressure pulses on the hull, is very small.

Such model tests, if required, shall be the sole responsibility and expense of the Contractor and **shall not** result in a change order to WSF.

## 1A.5 FLOW VISUALIZATION

If the Contractor's hull design deviates from WSF's optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform flow visualization model tests. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

If required, a program of general flow visualization tests and observations shall be carried out at the 16.45 ft. draft and ***design service speed*** (17 knots) using either the method of paint streaks or the method of wool tufts. The model shall be self-propelled by the stern (pushing) propeller.

Flow visualization tests using visual observations and still photography (and video if the method of wool tufts is employed) shall be performed to evaluate the flow over the hull. The test shall be recorded through a series of clear, sharp, still photographs, augmented as appropriate by sketches (and video if the method of wool tufts is employed).

Expert observations shall be made regarding the flow alignment and behavior. Recommendations (if any) regarding possible improvements to the hull form will be developed and reported.

## 1A.6 RESISTANCE TESTS

<u>WSF has identified low fuel consumption and minimized wake wash at the design service speed of 17 knots as the priority goals for the New 144-Auto Ferries Project.</u> The following Subsections set forth the trial speed, and maximum permissible power and wake wash for the Vessel's design. These performance measures shall be subject to verification during Sea Trials prior to Vessel delivery. If the Contractor's hull design deviates from WSF's optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform resistance model tests. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

If required, resistance tests shall be carried out at two (2) drafts, the ***design operating draft*** and the ***end-of-service life draft***. Two (2) conditions will be tested at each draft: ***1).*** bare hull with rudders; and ***2).*** bare hull with rudders and free-to-rotate, feathered, bow propeller. For the case of the bare hull with rudders condition, the tested speed range at each draft shall include slow speed tests suitable for the development of a Prohaska plot from which the form factor may be estimated. In all tested conditions the speed range will extend to a minimum of twenty (20) knots.

Prohaska plots shall be developed and provided for each of the two (2) drafts. The hull form factors shall be determined from the Prohaska plot and reported. The form factors shall be compared with form factors obtained from other similar vessels with which the model basin has experience. If the form factor recommended by the model basin for use in extrapolations to full scale is different from those derived from the Prohaska plot an explanation of the recommendation shall be provided. Experienced model basin personnel shall subject the Prohaska plot to expert review to ascertain if the character of the plot suggests anything important regarding the hull form and/or possible improvements to the hull form, or flow behavior during the slow speed tests.

Bearings for the free-to-rotate, feathered, bow propeller shall be designed to model the expected shaft bearing friction and other drive train losses associated with the free-to-rotate, feathered, bow propeller. A bench test shall be conducted and documented to establish the frictional resistance achieved by the model free-to-rotate, feathered, bow propeller. Alternatively, using a drive internal to the model, the model feathered propeller can be rotated at the calculated rotation rate, determined from $K_Q$ when feathered pitch is such as to minimize $K_T$ , given the expected shaft bearing friction and other drive train losses. ***Note that the bow propeller will feather with the leading edges forward (towards the bow rudder), which corresponds to extreme reverse pitch and is opposite to most feathering controllable pitch propellers****.*

The model basin shall provide full scale extrapolations of resistance for each condition tested. All model scale data shall be provided so that independent extrapolations using alternative methods may subsequently be carried out.

### 1A.6.1 Use of Model Basin Stock Propeller as Feathered Bow Propeller

A model basin stock controllable pitch model propeller may be used as the free-to-rotate, feathered, bow propeller provided that:

1. the model scale is chosen such that the stock propeller diameter is the same as that of the design propeller (D=11.5 feet).
2. the blade number is the same as that of the design propeller (Z=4).
3. the blade area ratio of the stock propeller is within ±10% of that of the design propeller.
4. $K_Q$ , when feathered pitch is such as to minimize $K_T$ , is within ±5% of that of the design propeller.
5. the pitch distribution of the model basin stock propeller is similar in character to that of the design propeller.

Otherwise a custom model controllable pitch propeller shall be manufactured and used in the test program.

## 1A.7 WAVE SIGNATURE

WSF has identified “minimized wake wash” as one of the priority goals for the New 144-Auto Ferries Project. The maximum permissible wake wash for the Vessel’s design will be no greater than the maximum peak-to-trough wave heights extrapolated from model tests at 300 feet (91.4 m), 600 feet (182.9 m), and 1,200 feet (365.8 m) off the Vessel’s longitudinal centerline. This performance measure shall be subject to verification during Sea Trials prior to Vessel delivery. If the Contractor’s hull design deviates from WSF’s optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform wave signature model tests during Phase II Technical Proposal. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

Wave signatures (record of free surface elevation at a fixed location) shall be measured in longitudinal wave cuts parallel to the Vessel trackline, with the Vessel proceeding at 17 knots in calm water at the ***design operating draft*** and again at the ***end of service life draft***. To the extent possible, within the width restrictions of the model basin, wave signatures shall be measured at a minimum of two (2) off-track distances and extrapolated using computational fluid dynamic (CFD) or appropriate theoretical methods to standard off track distances of 300 feet (91.4 m), 600 feet (182.9 m), and 1200 feet (365.8 m). Care shall be taken to identify the onset of contamination by waves reflected from the towing tank wall in each measured record.

## 1A.8 SELF-PROPULSION TESTS

WSF has identified minimized power as one of the priority goals for the New 144-Auto Ferries Project. The following sets forth the minimum trial speed and maximum permissible service speed fuel consumption for the Vessel's design. These performance measures shall be subject to verification during Sea Trials prior to Vessel delivery. If the Contractor's hull design deviates from WSF's optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform self-propulsion model tests during Phase II Technical Proposal. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

If required self-propulsion model tests shall be carried out at two (2) drafts, the ***design operating draft*** and the ***end of service life draft***. During the self-propulsion tests the model shall be outfitted with rudders and the free-to-rotate, feathered, bow propeller. Propeller/hull interaction factors (i.e., Taylor wake fraction, thrust deduction fraction and relative rotative efficiency) shall be determined over a speed range extending from a minimum no greater than 12 knots (full-scale) to a maximum of at least twenty (20) knots or a speed at least 0.5 knot greater than the speed corresponding to 100-percent (100%) of installed propulsion power (maximum continuous service rating), whichever is greater.

### 1A.8.1 Use of Model Basin Stock Propellers

A model basin stock propeller may be used as the stern (pushing) propeller in the self-propulsion tests provided that:

1. the model scale is chosen such that the stock propeller diameter is the same as that of the design propeller (D=11.5 feet).
2. the blade number is the same as that of the design propeller (Z=4).

3. the blade area ratio of the stock propeller is within ±10% of that of the design propeller.
4. the pitch distribution of the model basin stock propeller is similar in character to that of the design propeller.

If archival open water tests ($K_T$ and $K_Q$ vs. J) for the model basin stock propeller are used, the model basin shall certify that the archival test results are accurate and suitable for the self-propulsion tests. Otherwise new open water tests shall be conducted.

### 1A.8.2 Custom Model Propeller

If a custom model propeller is used for the self-propulsion tests, then a program of open water tests (determination of $K_T$ and $K_Q$ vs. J) of the model propeller shall be carried out over a range of advance coefficients from J=0.0 to an advance coefficient where $K_T \leq 0.0$.

### 1A.8.3 Service Speed

The minimum ***design service speed*** shall be 17 knots when operating at the ***mid-service-life draft***, as defined above, with zero at-rest trim, with a clean bottom and under fair conditions of wind and sea. The Main Engines shall achieve this seventeen (17) knot service speed at the maximum continuous shaft horsepower indicated in the Model Test Report contained in. See Section 50 of the Technical Specification for a general description of the propulsion system.

The power absorbed at 17 knots shall be measured during Acceptance Trials (see Section 101 of the Technical Specification) at the ***mid-service-life draft***, as defined above, beginning from a condition of zero at-rest trim.

### 1A.8.4 Trial Speed

The minimum acceptable trial speed shall be the speed indicated in the Model Test Report contained in as achievable at the maximum continuous rating for the Main Engines. This is the speed that can be achieved with a clean bottom, under fair conditions of wind and sea, at, but not exceeding, the maximum continuous service rating for the Main Engines and with all vital gages reading within normal operating limits.

The minimum design trial speed shall be demonstrated during Acceptance Trials (see Section 101 of the Technical Specification) at the ***mid-service-life draft***, as defined above, with zero at-rest trim.

## 1A.9 DETAILED WAKE SURVEYS

WSF has carried out a detailed three-dimensional wake survey for the WSF optional hull form. If the Contractor's hull design deviates from WSF's optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform new detailed three-dimensional wake surveys during Phase II Technical Proposal. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

If required, the detailed three-dimensional wake surveys shall be carried out in both the bow and stern propeller planes of the final hull design. The wake shall be measured using either a 5-hole pitot tube or a laser-Doppler velocimeter. If a 5-hole pitot tube is used, the measuring head shall be small compared with the distance between radial measuring points. The model scale shall be such that the model scale propeller disk has a diameter of at least 7.3 inches. A harmonic analysis, to a minimum of twenty (20) mathematical terms, shall be performed of the longitudinal, radial and tangential wake at radii extending from the hub to at least 105-percent (105%) of the design propeller diameter.

Wake measurements shall be made at every 0.1 R at angular spacing no greater than fifteen (15) degrees. The spacing of radial and circumferential measurements shall be increased in areas where viscous wake concentrations of vorticity are expected. The finer mesh shall be sufficient to characterize any local wake peaks or vorticity.

## 1A.10 MANEUVERING

The double-ended ferry must satisfy the following described minimum requirements pertaining to slow speed maneuvering and to maneuvering at speed. These capabilities must be demonstrated by the completed Vessel during Acceptance Trials.

If the Contractor's hull design deviates from WSF's optional hull form by more than a minimal amount, as defined above under the *GENERAL* Subsection in this Section of the Technical Specification, then WSF may determine that the Contractor must perform maneuvering model tests during Phase II Technical Proposal. All expenses associated with any such model tests, if required, are the sole responsibility of the Contractor and **shall not** result in a change order to WSF.

In addition to maneuvering tests required during Acceptance Trials and model tests that may be required if the Contractor's hull deviates from WSF's optional hull form, these requirements also specify formal design, analysis and simulation required during the Phase II Technical Proposal.

### 1A.10.1 Bollard Lateral Thrust

The bollard (zero forward speed) lateral thrust of the stern (pushing) propeller and design rudder shall be measured at the ***mid-service-life draft*** under two (2) propulsion power conditions: ***1).*** with the pushing propeller absorbing 95-percent (95%) of maximum continuous rating (MCR) for the Main Engines (5,700 BHP); and ***2).*** with the pushing propeller absorbing 50-percent (50%) of MCR (3000 BHP).

The bollard lateral thrust shall be determined as a function of rudder angle from five (5) degrees up to a minimum of thirty-five (35) degrees or the maximum provided by the proposed steering system if greater than thirty-five (35) degrees. Measurements shall be taken at five (5) degree increments except in the vicinity of stall where finer steps shall be taken as necessary to establish the character of the model scale stall peak.

Care shall be taken to minimize scale effects acting on model rudder stall. While measures to minimize such scale effects are left to the model basin, it is suggested that local turbulence stimulation (e.g., sand strips on the rudder) be considered.

Minimum values for the maximum bollard lateral thrust achievable at any rudder angle by the rudder at one End of the Vessel are 176,000 lbs (783 kN) at 95-percent (95%) MCR and 92,000 lbs (409 kN) at 50-percent (50%) MCR.

The maximum bollard lateral thrust shall be demonstrated during Acceptance Trials (see Section 101 of the Technical Specification). If the Contractor's hull, rudder or propeller design deviates by more than a minimal amount from WSF's optional hull form, then bollard lateral thrust model tests may be required.

### 1A.10.2 Slow Speed Maneuvering

Maneuvering tests shall be conducted during Acceptance Trials demonstrating the ability of the completed double-ended ferry to 'walk' sideways with essentially zero speed either forward or aft. This shall be accomplished at the ***mid-service-life draft*** by pitching propellers at both ends of the double-ended ferry for ahead thrust and independently operating the rudders at opposite Ends.

If the Contractor's hull, rudder or propeller design deviates by more than a minimal amount from WSF's optional hull form, then a combination of model tests and analysis may be required during the Technical Proposal preparation to demonstrate predicted compliance with this requirement.

### 1A.10.3 Crash Stopping

The crash stop maneuver is of particular importance to a double-ended ferry because the docking maneuver, which is repeated numerous times each operating day, is in essence a crash stop maneuver.

During the Technical Proposal preparation phase the Contractor shall prepare and submit for WSF review and approval a time-domain simulation of the crash stop process at the ***mid-service-life draft*** beginning from a speed of seventeen (17) knots. It is not the intent of this Technical Specification to set forth every element of such a simulation or to specify the data sources for the various engineering factors that enter into such a simulation. However, the following identifies some of the elements known to WSF and suggests a minimum level of detail that may be approved:

- Hydrodynamic added mass should be included.

- Hull interaction factors (i.e., Taylor wake fraction, thrust deduction fraction and relative rotative efficiency) acting at the bow propeller plane should be included. If determined to be significant, the dependence of such hull interaction factors on forward speed and/or braking thrust should be included in the time-domain model.

- Mechanical losses in the propulsion drive train (e.g., shaft bearing friction, gear losses, etc.) should be included.

- The thrust and torque characteristics of the bow propeller acting in a braking mode (i.e., astern speed and forward thrust) must be considered. These characteristics are typically regarded as a function of a hydrodynamic angle defined in terms of speed of advance in the (bow) propeller plane and the propeller RPM. These thrust and torque characteristics are parametrically dependent on the instantaneous propeller pitch ratio (P/D). Ideally, these characteristics would be determined from tests in a cavitation tunnel or de-pressurized towing tank. Alternatively, these characteristics may be predicted by a lifting surface program capable of addressing unsteady cavitating propellers, equal or superior to PUF-3A (as developed at MIT by Kerwin, Kinnas and others).

- The dynamic performance of the diesel prime movers, including available torque versus RPM, and the ability of the diesel prime mover to accelerate (considering factors such as turbo-charger lag) should be included.

- The design characteristics and programs of the integrated Diesel-CPP Control System during a crash stop evolution should be included.

- The pitch changing rate capabilities of the bow and stern propellers should be included.

- To the extent that the stern propeller remains engaged throughout the crash stop evolution, identify the power absorbed/diverted to the stern propeller.

The Contractor is encouraged to carry out those additional model test experiments that will contribute towards a high confidence in the time-domain simulation of the crash stop maneuver.

The time-domain simulations shall, as a minimum, include (all as functions of time): Vessel advance distance, pitch and RPM of bow and stern propellers, and torque and thrust of bow and stern propellers. Other system properties determined to be of importance to the performance modeling (e.g., turbocharger RPM, control system signal states, etc.) should also be output.

For a crash stop maneuver in deep water at the ***mid-service-life draft***, beginning from an ahead speed of seventeen (17) knots in deep water, the head reach and stopping time shall be determined. The following shall not occur during the crash stop maneuver: ***1).*** engine stall; or ***2).*** engine operation outside the engine operating range warranted by the engine manufacturer for transient overload conditions (ISO Overload Power). Compliance with these requirements shall be demonstrated by the time-domain simulations and by propulsion system dynamic analyses as described in Section 50 of the Technical Specification, and during trials of the completed Vessel.

### 1A.10.4 Deep Water Maneuvering at Service Speed

Maneuvering tests shall be conducted at the ***mid-service-life draft*** during Acceptance Trials, demonstrating compliance with IMO Resolution A.571(18) as regards turning circles, zigzags and direct spirals. The maneuvering trials shall be carried out with zero at-rest trim, from an initial speed of seventeen (17) knots.

The residual rate of turn (at zero rudder angle) determined from pull-out tests or by either spiral or reverse spiral tests, shall not exceed 0.25 degrees. The spiral loop width determined from either spiral or reverse spiral tests shall not exceed 5.0 degrees total, or 2.5 degrees to each side.

Trials of the completed Vessel to demonstrate compliance with these requirements shall include turning circles, pullouts, and either direct spiral or reverse spiral tests.

If the Contractor’s hull, rudder or propeller design deviates by more than a minimal amount from WSF’s optional hull form, then a combination of model tests and analysis (maneuvering simulation) may be required during the Phase II Technical Proposal to demonstrate predicted compliance with this requirement.

## 1A.11 CAVITATION AND PROPELLER INDUCED VIBRATIONS

If the hull lines vary beyond the allowable margins described above, a new wake adapted propeller design, cavitation prediction and estimation of unsteady forces and pressures shall be required. This redesign shall be carried out by the PSI Contractor at the sole expense of the Contractor, using Contractor provide hull form and wake survey model test data.

### 1A.11.1 Propeller/Hull Clearances

Any modification to the hull form shall require that the closest approach of the propeller blade tips to the hull, measured in any direction, shall not be less than 13.8-percent (13.8%) of the propeller diameter.

### 1A.11.2 Wake Adapted Propeller Design and Cavitation

Should the Contractor modify the hull form, the scope of work for the new Wake Adapted Propeller Design shall be as follows:

A wake adapted propeller shall be developed using lifting line **<u>and</u>** lifting surface methods. In the following, nominal full power (100% MCR) is understood to be 6,000 BHP. Hull form, resistance, hull-propeller interaction factors, and detailed wake at 17 knots are to be determined from model tests performed at a scale ratio not greater than 18:1. The goals of the propeller design shall be as follows:

A. Maximize propeller efficiency when operating at 17.0 knots.

B. There should be **<u>no</u>** face or back cavitation when operating at seventeen (17.0) knots under fair wind and sea conditions (nominal 17 knot self-propulsion point from trials prognosis using final design propeller).

C. Pressure pulses on the hull shall be minimized at 17.0 knots with the intent of minimizing propeller induced hull vibratory forces.

D. Back cavitation at 17.0 knots at 85% power shall not exceed 5-percent (5%).

E. Back or face cavitation in the full power trial speed condition shall not exceed 5-percent (5%).

F. Cavitation should be minimized when engaged in low speed maneuvering operations, thrusting ahead or astern at 50-percent (50%) power at any speed between -8.0 and +8.0 knots.

G. The unsteady component of propeller thrust shall be minimized when operating at 17.0 knots.

H. The unsteady blade bending moments shall be minimized at 17.0 knots.

I. Maximum controllable pitch blade spindle torque should be minimized over the range of from full ahead pitch to and full-feather (extreme astern) pitch, operating conditions.

J. The propeller design shall provide anti-singing edges on the trailing edges of the blades.

K. The blade design shall be subjected to a finite element structural analysis. As a minimum, the finite element analysis shall consider both steady and unsteady blade loading in the following cases: ***1).*** full power ahead at 17.0 knots; ***2).*** bollard condition ahead at 100-percent (100%) of full power; ***3).*** bollard condition astern at 70-percent (70%) of full power; and ***4).*** bow propeller at 110-percent (110%) of full power, generating braking force by thrusting ahead during a crash stop, at forward speeds between 17 and 0 knots (limit state stress case only). Structural analysis shall consider both limit states and fatigue (excepting the bow propeller braking during a crash stop which may be limit state only). Design for fatigue shall be for not less than $2 \times 10^8$ cycles.

L. The design of the blade tip shall be developed with due consideration given to the fact that the Vessel will operate in waters containing floating debris hazards such as logs. The thickness of the blade tip should be increased above minimum normal practice to provide increased resistance to impacts with floating debris.

It is recognized that several of the goals cited above involve minimizing or maximizing selected performance properties. The Contractor shall advise WSF if two (2) or more of these goals are determined to be in opposition, and WSF will participate in establishing priorities amongst such opposing goals.

**TABLE 1A-2** summarizes the primary design goals regarding propeller performance and cavitation.

| TABLE 1A-2<br>Wake Adapted Propeller Design Cases | | | | |
|---|---|---|---|---|
| **Speed (knots)** | **% SHP** | **Thrust Direction** | **Performance** | **Cavitation** |
| 17.0 | As Required | Ahead | Maximize Propeller Efficiency | No face or back cavitation |
| 17.0 | 85 | Ahead | --- | <5% back |
| Maximum | 100 | Ahead | --- | <5% |
| 17.0 to 0.0 Crash Stop | 110 (ISO Overload) | Bow Propeller Ahead | Maximize Braking Thrust | Minimize, No Thrust Breakdown |

A lifting surface program equal to PUF-3A shall be used to evaluate cavitation and off design operating conditions, including those four-quadrant operating conditions necessary to meet the propeller design goals and the maneuvering simulation requirements. To be considered equal to PUF-3A, a program must be capable of computing the growth and collapse of unsteady cavitation bubbles for a propeller operating in a non-uniform wake, and it must be capable of predicting the unsteady forces of both non-cavitating and cavitating propellers (including unsteady or intermittent cavitation) when operating in a non-uniform wake. A program proposed as an equal to PUF-3A must be proven and well accepted. Evidence (e.g., correlation studies between model and predicted performance) shall be provided that documents the required capabilities of the program if a lifting surface program other than PUF-3A is proposed.

The nominal propeller tip velocity, $\pi$ DN/60, (where D is the propeller diameter in feet and N is the propeller RPM) shall be less than or equal to 110 fps.

All sources of unsteady propeller induced pressure on the hull shall be predicted, including blade thickness, mean blade loading, wake harmonic effects and cavitation. Hull pressures may be estimated as double the free-field value (flat plate assumption). Any reductions from double the free-field pressures must be justified by suitable correlation data. For all operating conditions shown in **TABLE 1A-2**, excepting the crash stop, the peak propeller induced pressure pulse on the hull (magnitude of peak deviation from mean), due to all causes, shall not exceed 2.2 psi.

It is preferred that the propeller induced pressure pulse amplitudes on the hull, directly above the propeller tips, not exceed 1.1 psi at blade frequency and 0.5 psi at twice blade frequency.

Model tests of the final propeller design are contingent on the results of the propeller design calculations regarding cavitation and propeller induced pressure pulses on the hull. No model tests of the final design propeller are required if the propeller design calculations indicate that the margins against the following are adequate: ***1).*** exceeding the cavitation limits; and ***2).*** exceeding the propeller induced pressure pulses on the hull. Margins that provide at least 95-percent (95%) confidence that the limits will not be exceeded are regarded as adequate for the purposes of this requirement. The WSF Representative's determination requiring the necessity for scale model tests of the final design propeller shall be final.

Such model tests, if required, shall be the sole responsibility and expense of the Contractor and **shall not** result in a change order to WSF.

### 1A.11.3 Model Tests of Final Propeller Design

A scale model of the final design propeller(s) must be constructed and tested in either a large cavitation tunnel or a depressurized towing tank. It is preferred that, if such a model is constructed, that it be tested with the model of the final hull design, as used for calm water experiments, so that propeller induced pressure pulses can be measured on the hull.

Alternatively, but less satisfactorily, the final design propeller model may be tested in a small cavitation tunnel. If tests are conducted in a small cavitation tunnel, then the tunnel shall be sufficiently large to include, as a minimum and without unacceptable blockage, a scale model of the after-body, a false scale fore-body transition, and a model propeller of sufficient diameter to achieve, as a minimum, a Reynolds number of $5 \times 10^6$ at the 0.7 propeller radius or a 5 inch propeller diameter, whichever is larger.

The test program shall be so designed as to demonstrate and confirm that the final design propeller meets the cavitation and hull induced pressure goals. Data obtained from this test program shall be incorporated in the Contractor's program of hull and local structure vibration analysis.

Such model tests, if required, shall be the sole responsibility and expense of the Contractor and **shall not** result in a change order to WSF.

## 1A.12 MODEL TEST DATA AND REPORTING

All reports shall be written in English. A minimum of six (6) copies shall be provided of all reports.

All time domain data, regardless of subsequent analysis, shall be recorded and delivered as digital time series data on permanent media such as CD-ROM(s) or DVD-ROM(s). ASCII files are preferred. All files shall be clearly identified as to test I.D., contents, channel identifications, units, and any required scale, conversion or calibration factors. An index to these data files shall be provided as a file on the permanent media. A minimum of three (3) complete sets of all recorded data shall be provided.

Still color photos shall be taken of all models and all test set ups. Representative still color photos shall be provided for each major test series. If paint streak methods are used for flow visualization, then the test shall be recorded through a series of clear, sharp, still photographs augmented as appropriate by sketches.

Color videos recorded in DVD format shall be provided for selected test series. As a minimum, the test series for which video shall be provided shall include:

A. Flow visualization (if wool tufts are used)

B. Still water resistance

C. Propulsion

D. Maneuvering tests

Video sequences shall be preceded by titles identifying the test sequence that follows and significant parameters (e.g., speed, wave height, wave period, etc.). A minimum of three (3) copies of the videos shall be provided.

## 1A.13 PHASE II TECHNICAL PROPOSAL REQUIREMENTS

If the Contractor's hull, rudder, or propeller design deviates by more than a minimal amount (as determined by the WSF Representative) from WSF's optional hull form, then one (1) or more (as determined by the WSF Representative) of the following deliverables, in addition to those required by Section 100 of the Technical Specification and the Authoritative Agencies, shall be submitted during the Phase II Technical Proposal phase of work in accordance with the requirements of Section 100:

A. Resistance and Propulsion Model Test Reports

B. Speed and Power Analysis Report

C. Fuel Consumption Analysis Report

D. Crash Stop Simulation Report

E. Wake Adapted Propeller Design Report

F. Flow Visualization Model Test Report

G. Detailed 3-D Propeller Plane Wake Survey Model Test and Harmonic Analysis Report

H. Slow Speed Maneuvering Predictions

I. Deep Water Maneuvering Simulations Demonstrating Compliance with IMO Resolution A.571(18)

J. Free Running Wave Signature Measurements and Predictions Report

Contingent on the outcome of the cavitation and propeller induced hull pressure predictions in the Wake Adapted Propeller Design Report, the following report may also be required during Phase II Technical Proposal:

K. Cavitation Model Test Report

The ***Crash Stop Simulation Report*** and, if required, the ***Slow Speed Maneuvering Predictions***, shall include sufficient data to verify compliance with the requirements of the *MANEUVERING* Subsection in this Section of the Technical Specification. The report should clearly indicate the basis of each prediction, whether it be analytical, based on model tests, or some other reliable source. Compliance with the crash stop requirements shall be demonstrated by a time domain simulation. This requirement may be satisfied by the propulsion system dynamic analyses described in Section 50 of the Technical Specification provided that those analyses provide reliable evidence that the crash stop requirements of the above *MANEUVERING* Subsection in this Section of the Technical Specification are satisfied. The crash stop analysis must consider the actual performance of the propulsion control system, the hull hydrodynamics (including added mass), and the actual performance of the design wake adapted propeller.

The ***Wake Adapted Propeller Design Report*** shall include performance, cavitation, induced pressures analysis, and structural calculations as required by the above *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification. As a minimum the report shall compare predictions for the Contractor's wake adapted propeller with the requirements of the *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification. The report should clearly indicate the basis of each prediction, whether it be analytical, based on model tests, or some other reliable source. The report shall include open water propeller characteristics ($K_T$ and $K_Q$ vs. J) in the first performance quadrant for all pitch settings between zero and (and including) maximum pitch achievable, in P/D increments no larger than 0.1. The report shall include sufficient definition of propeller characteristics in other operating quadrants to support the required analysis of slow speed maneuvering performance and crash stop performance.

As provided for by the above *CAVITATION AND PROPELLER INDUCED VIBRATIONS* Subsection in this Section of the Technical Specification, model tests of the final wake adapted propeller design will be required if the design calculations indicate that the margin against exceeding the cavitation limit is small and/or the margin against exceeding the induced pressures on the hull is small.

Additional deliverables related to various requirements of this Section of the Technical Specification are addressed in the following Sections of the Technical Specification:

| TOPIC | SECTION |
|---|---|
| Hull lines and offsets | Section 1C |
| Rudder arrangement and details | Section 2 |
| Propellers | Section 53 |
| Propulsion system vibration | Section 102 |
| Structural vibration | Section 102 |

## 1A.14 PHASE III DETAIL DESIGN AND CONSTRUCTION REQUIREMENTS

(Not Used)

## 1A.15 WSF OPTIONAL HULL FORM

**FIGURE 1A-1,** Lines Plan attached to the end of this Section of this Technical Specification provides a representation of the salient features of optional hull form lines and shall to be referred to as set forth in this Section of the Technical Specification.

**(END OF SECTION)**